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MITIGATION MEASURES FOR WHEAT PRODUCTION UNDER HEAT STRESS CONDITION

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ABSTRACT

Climate change is a reality and agriculture is highly vulnerable. The changing climate could strongly affect the wheat production worldwide. Among various factors affecting wheat productivity high temperature has a significant effect. The terminal heat stress is prevalent in the major wheat growing regions of Indo-Gangetic Plains. The increasing temperature shortens the duration of both vegetative and reproductive phases. The effect of increasing temperature during reproductive phase is more harmful than that of the vegetative phase. Selection of early maturing varieties escapes from heat stress and varieties having terminal heat stress tolerance can cope up with high temperature during the grain filling stage. Timely sowing of wheat crop is beneficial in mitigating heat stress as it gives higher yield than sowing the crop late in the season. Late sown wheat crop makes the ripening stage of the crop coinciding with high temperature stress. Late planting also causes reduction in the duration of tillering period and leads to forced maturity thus reducing the grain yield due to exposure to hot weather during the critical stage of crop growth that is the grain filling period. Planting technique of wheat that includes zero tillage, bed planting, conventional tillage with mulching and surface residue retention increases grain yield as compared to conventional tillage. Also provision of additional irrigation water at critical stages and skipping during the dough and ripening stages increases the yield of wheat under high temperature. Application of certain chemicals can help in mitigating the adverse impact of high temperature stress.

KEYWORDS: wheat, Heat Stress, Early Maturity, Zero Tillage, Mulching & Residue

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INTRODUCTION

Wheat (*Triticum aestivum L) is the second most important* staple food crop of the world. It accounts nearly 30% of global cereal production covering an area of 220 million hectare with an average productivity of 3.2 tonnes ha^{-1}(FAO, 2015). Wheat production in the year 2013-14 was recorded as 95.91 million tonnes covering an area of 30 million hectare in India (DES, 2014). The country further required 100 million tonnes of wheat by the year 2030 to fulfill the demands of the growing population which poses a major challenge in the background of prevailing changed climatic scenario. Crop performance and yield is the ultimate result of interaction of a crop genotype and its environment. Among various stresses, abiotic stresses such as heat, drought and salinity are considered as major threats to sustainable wheat production in India. According to world estimates, average yield losses in agricultural crops up to 50% is mainly due to different abiotic stresses as a result of these changing climatic conditions (Theilert, 2006). The growth and yield of wheat crop is adversely affected by different

environmental stresses like high temperature, soil moisture deficit, low light intensity etc. High temperature is considered to be most important factor to reduce the wheat yield among the various stresses (Trnka *et al*., 2004: Joshi *et al*., 2007 and Modarresi *et al.,* 2010). Heat stress depends on heat intensity which is a measure of rise in temperature above the environmental temperature, duration of exposure to high temperature, rate of rise in temperature and the response of plant to high temperature at different developmental stages. It implies alteration in diverse metabolic processes that normally required for optimum plant growth which finally leads to qualitative and quantitative loss of the produce and extremity of this could lead to plant death. In developing countries, about 7 million hectare of wheat is subjected to continual heat stress and terminal heat stress is poses serious threat to about 40 per cent of the temperate environments accounting for 36 million hectare of wheat. Spring wheat which is normally grown in these areas faces severe heat stress during certain phases of crop growth. The Indo-Gangetic Plains (IGP) of India, Nepal, Bangladesh and Pakistan is an important region of rice-wheat cropping system that covers about 13.5 million hectares area (Gupta and Seth, 2007) and contributes about 40% of the country's total food grain basket (Saharawat *et al*., 2010) are subjected to heat stress due to the prevalence of conventional tillage practices. The conventional planting system of wheat which involves repeated dry tillage for preparation of the field followed by broadcasting of wheat seeds that is responsible for delay in wheat seeding by almost a week as compared to zero tillage. Because of the shorter growing period available for wheat growth along with its delayed planting due to above reasons, wheat crop exposes to high temperature during the gain filling stage that is the terminal heat stress leads to drastic loss in yield. Though the terminal heat stress can be prevented to some extent by providing irrigation water at grain filling stage which makes the plant adaptation to heat stress, most farmers in Eastern IGP suffer from the economical access to irrigation water thus leading to yield losses upto 30% as a result of terminal heat stress in wheat(Malik *et al*., 2014). According to the estimation of IPCC, 2007 it is clear that the temperature is going to increase between 1.1-6.4°C by the end of 21st century. Earth will be warmer by 2.4°C and crop yield will fall upto 30% by 2020 (Anonumous,2011). It has been estimated that the global mean temperature is steadily increasing which could lead to significant decline in wheat yields in South Asia by 2050 (IFPRI, 2009). The average monthly temperature trend for 10 years in Varanasi region of Uttarpradesh which is a major wheat growing region was observed. The average temperature of the wheat growing season was recorded and from the temperature trend it was evident that the temperature is highly fluctuating from year to year **(figure 1).** The maximum temperature in these months are having higher deviation from the mean during the anthesis stage of wheat whereas the minimum temperature showed increasing trend during 2010-15 than the last 5 years (AICRPDA, BHU).This review paper lays emphasis on the harmful effect of high temperature and mitigation strategies to cope up with the heat stress on wheat.

EFFECT OF HIGH TEMPERATURE ON WHEAT

Wheat is physiologically thermo-sensitive long-day crop as a result of which the accumulation of heat or temperature units above threshold or base temperature (below which no growth occurs) is required for the optimum phenological development starting from sowing to maturity. A specific value of heat or temperature units is required for wheat crop to reach a particular phenophase. Temperature is an important determinant in physioloical and morphological development influencing the growth, development and yield of crops. Heat stress adversely affects the wheat crop starting from the early stage of emergence in wheat. Exposure of wheat seedling to heat stress for a short period can also cause significant decrease of the root and shoot length, dry mass, chlorophyll content as well as membrane stability index which is a measure of tolerance of cell membrane to sustain in high temperature (Gupta *et al.,* 2013). High temperature particularly during sowing time in the month of November makes the crop to reach jointing stage too early by accelerating

the rate of growth thereby reducing the required period for tillering (Harrison *et al*., 2000). This ultimately results in reduced number of tillers due to less accumulation of heat units finally leading to decline in the total crop yield. Similarly exposure to high temperature at flowering and grain filling stages causes reduction in the duration of grain filling which leads to early maturity and hence reduces the crop yield. Exposure to heat stress accelerates the growth rate and developmental stages in wheat crop to such an extent which cannot be supplemented by supply of essential inputs like solar radiation, water and nutrient) (Tandon, 1985; Laghari *et al*., 2012 and Blum *et a.*,, 2001). In wheat, period from onset of spike ignition to flowering is very sensitive to temperature. High temperature is sometimes found to be accompanied with drought and the combined effect of these have adverse effect on reproductive development such as flower initiation, ovary and pollen development, fertilization leading to reduction in sink potential which further results in yield loss (Barnabas *et a.*,, 2008). Heat stress ultimately has detrimental effect on the production of wheat by causing reduction in biomass, tiller number, duration of grain filling, kernel size, etc. as a result of its adverse impact on days to appearance of first node, tiller per plant and spikelets per plant, thereby resulting in reduction of sink capacity and future sources capability of the plant (Sharma *et al*., 1997). It was estimated that an increase in temperature up to 0.5°C reduced the duration of crop by seven days, resulting in yield loss of 0.5tha^{-1} in North India (Parry *et al*., 1992). High temperature after flowering stage accelerates leaf senescence, thereby reduces grain filling stage and thus decreases grain yield (Ford *et al.*, 1975). Under high temperature conditions, tillering and root growth are reduced but heading and maturity are accelerated. Wheat exposes to heat stress to varying degrees at different phenological stages, but the exposure of the reproductive phase to heat stress is more harmful than exposure during vegetative stages due to its direct effect on grain number and dry weight (Wollenweber *et al*., 2003). Grain number is generally determined from 30 days before anthesis and grain size is determined during the rain filling stage. In the Indo gangetic plains grain filling stage coincides with high temperature and slows down the photosynthesis and grain filling rates leading to smaller grain size and lower yield known as terminal heat effect (Lobell *et al*.,2012). Ideally it was reported that the best temperature regime at different stages for optimum growth and yield of wheat crop is: 20–22 °C at sowing, 16–22 °C at tillering to grain filling and a slow rise of temperature to 40 °C at harvesting (Sharma, 2000). Heat stress is also identified as a major factor for end-use quality of wheat. It was further observed that temperature is positively correlated with the sedimentation values, soluble and insoluble proteins, and mixograph peak height that is the increase in temperature leads to increase in these values and vice versa whereas the flour yield, mixing time and mixing tolerance of the dough were found to be significantly reduced as a result of rapid desiccation during ripening (Tahir *et al*., 2005). The grain protein content was also found to increase significantly due to post-anthesis exposure to heat stress but on the other hand the glutenin/gliadin ratio which determines the flour quality followed an opposite trend that is its value decreased in response to heat stress (Ashraf, 2014).

EFFECT ON PHYSIOLOGICAL PARAMETER

Physiologically yield of a crop depends on the photosynthesis and ability of grains to utilize photosynthates for its growth and high temperature has adverse impact on both these processes. Photosynthesis is affected adversely by reducing the various physiological parameters like chlorophyll content, efficiency of PSII, net assimilation rate, transpiration, stomatal conductance and intercellular CO_2 concentration under heat stress condition. Heat tolerance in wheat can be determined by considering together physiological and yield parameters (Balla *et al*., 2014). Photosynthesis is a key physiological process in plants that involves various enzymatic reaction thus making this process very susceptible to heat stress.

Heat stress results in deactivation of the key enzyme *Rubisco w*hich involves in photosynthesis as a result of lower concentration of CO_2 due to closing of stomata. Decreased activity of *Rubisco* under heat stress condition has also been reported in wheat, maize, cotton and tomato (Ashraf and Harris, 2013).

Generation of reactive oxygen species like partially reduced forms of oxygen like super oxide radical (O^{2-}), hydrogen peroxide (H_2O_2) and hydroxyl radical (OH^-) in excess that leads to oxidative stress by destruction of cellular components like membranes and macromolecules is one of the major consequences of heat stress in plant.

Plant cell maintains cellular homeostasis by scavenging reactive oxygen species using enzymes such as superoxide dismutase, catalase, peroxidase, ascorbate peroxidase and glutathione reductase and non-enzymatic antioxidants such as tocopherols, ascorbic acid, glutathione and carotenoids. Decresed activity of catalase and enhanced activity of superoxide dismutase, peroxidase, ascorbate peroxidase and proteases were also reported in wheat seedling as a response to heat stress during heat induced programmed cell death (Hameed *et al*., 2012).

MITIGATION MEASURES

Selection of Varieties

Selection of appropriate variety with respect to date of sowing is important to cope up with the expected temperature rise during the crop period and to get an optimum yield under high temperature stress conditions in wheat crop. Varieties like PBW-343 and DBW-17 have flexibility, adaptability and are suited to different sowing times. The variety PBW-343 was released for the northwestern India primarily because of its wider adaptability in terms of temperature and water stress tolerance. PBW-343 was the predominant in the rice-wheat growing areas, where sowing can often be delayed because of later harvest of second rice crop and/or managing stubble from the rice crop (Malik *et al.*, 2007). Also the varieties like PBW-373 and kaushambi (HW 2045) possess terminal heat stress tolerance and Naina (K- 9533) and Parbhani-51 are heat tolerant varieties which on adoption for sowing can overcome the adverse effect of high temperature on wheat crop(DWR Perspective Plan Vision 2025).

Heat tolerant varieties can be judged from its heat killing time which is the indicator of cell membrane thermostability. Time required to reach 50% membrane injury in a genotype was considered to be its heat killing time. The variety which is having defence mechanism like early maturity, leaf rolling, stay green, intensive transpiration can cope up with this high temperature stress and manage to produce stable yield under this changing climate scenario. The traits like early ground cover, chlorophyll content, canopy temperature depression, stem reserve mobilization and antioxidant defense system can be selected while going for breeding for heat tolerant varieties.

Sowing Time

Time of sowing is one of the non-monetary inputs for getting optimum growth and yield in wheat crop according to prevailing agro climatic conditions and genotype. Sowing time can be manipulated to prevent the hot and desiccating wind during flowering and grain filling period that ultimately determines the yield of the crop. The performance of wheat varies with different dates of planting. The optimum time of sowing for wheat crop in India is first fortnight of November. The sowing of crop is delayed that is upto first fortnight of January mainly because of late harvest of paddy crop, delay in field operations, climate changes etc. Crop sown in mid November shows better growth and maximum plant height (84.3cm) than rest of sowing dates which is followed by late November sowing (78.6cm) as reported by Mukherjee, 2012. Singh *et al.*, 2008 and Singh *et al.*, 2000 also reported the same results. This result may be attributed to the fact that the rise

in temperature which makes the crop to enter into the next stage without much development required for the succeeding stage. It was reported that crop sown on 20th November produced significantly more leaf area index (4.4) than that of 20th December (3.9) sown crop (Khichar *et al*., 2007).

Also, the delay in sowing reported to reduce the LAI (Ram *et al.*, 2012a). The experiment also concluded that at 50 and 90 DAS the LAI is significantly higher in 15 December sowing as compared to 1 January one. Scorching of leaves and twigs, sunburns on leaves, branches and stems, leaf senescence and abscission caused by the high temperature stress are the main cause of lower leaf area index in late sown crop. Dry-matter accumulation was also significantly higher with timely sown crop (879.9 gm^{-2}) than late sown crop (662.6 gm^{-2}). However, plant height, dry matter accumulation and tillers per meter row length were significantly higher in early sown crop of 25th November than late sown crop of 10 December. So that early sown wheat crop was superior to late sown crop in various growth parameters (Davinder, 2010). Jat *et al.*, 2013 showed that the crop sown on 20th November achieved maximum height, dry-matter accumulation plant^{-1} and number of tillers than rest of sowing dates. The reason for this is the maximum growing period length availability in 20th November sowing which leads to higher accumulation of growing degree day and photothermal unit. Dry matter accumulation was decreased with delay in sowing from timely (21st November) to very late (7th January) (Shivani *et al.*, 2003).Similar results were reported by Nainwal *et al*., 2000 which showed maximum reduction in growth attributes of late sown crop. This might be due to lowering of temperature which results in decrease in cell activity like cell division and expansion, which decides the yield attributes like number of tillers, spikes, fertile spikelets etc reducing the ultimate yield of the crop. High temperature also found to decrease grain numbers (by 56 % averaged across both experiments) and individual grain weight (by 25 %) (Prasad *et al.*, 2011).Maximum grain yield was recorded from the crop sown on 15th November and significantly differed from crop sown in December and January (Samra *et al.*, 2002). It could be concluded, the growth parameters are adversely affected by delayed sowing of wheat which leads to forced maturity because of high temperature prevailed during reproductive phase of the late sown crop. Due to that maximum grain yield was recorded in early sown wheat crop in comparison with late sown crop. The grain yield of wheat under early sown crop could be attributed to better basic infrastructural frame work of plants in early sowing as supported by higher taller plants, dry matter accumulation, tillers per meter row length, number of effective tillers per unit area, number of grains/ear, 1000-grain weight, ear length, straw yield and also utilized higher growing degree days and photo-thermal units.

High temperature stress also affects the quality parameter of wheat which is decided by two types of protein that is structural protein (albumins– globulins and amphiphils) accumulated in the grain mainly during the cell- division stage, and the other is storage protein (gliadins and gluteins) accumulated mainly during the grain filling period (Triboi *et al.*, 2003). In timely sown crop low temperature occurs after flowering stage as compared to late sown one, which causes reduction in accumulation of structural protein due to reduction in cell division at low temperature and also there in increase in filling period which leads to accumulation of more starch and less storage protein in the grain, as protein is inversely related to carbohydrate accumulation (Torbica *et al.*, 2008). High temperature during grain filling period reduces the yield which is because of reduction in starch accumulation (65% of grain dry weight is due to starch content of that grain).However, the effect of temperature on protein content of wheat is unclear and varies with type of genotype (Beata *et al.*, 2008). The late sown crop had maximum protein, ß-Carotene, gluten content, sedimentation value as compared to normal and early sown crop (Singh *et al*., 2000, Kumar *et al.*, 2002).It is evident that the rise in temperature makes the crop to enter into the next stage without much development required for the succeeding stage which leads to decreased crop duration, lower accumulation of photothermal unit, growing degree day coupled with low relative humidity.

Tillage Practices

Tillage practices and method of planting plays an important role in the placement of seed at proper depth, which ensures better emergence and subsequent crop growth. Wheat is planted using different planting methods depending upon the available soil water, time of planting, amount of residue in the field and availability of planting machine. The resource conservation technologies like no-till and zero tillage system that involves minimum disturbance to soil regime and maintenance of plant residues which in turn protect seedlings from high temperature during its initial growth period and keeps soil temperature down during the day and reduces cooling at night and also helps in conserving moisture. This helps the plant in carrying out metabolic activities with the same pace thus avoiding forced maturity. Also due to availability of moisture the crop can cope up with the demand of increased transpiration which in turn keeps the canopy temperature lower and reduces the terminal heat stress by delaying senescence in plant. Zero tillage was found to improve yield attributes, viz. plant height, effective tillers/m, grains per ear as compared to conventional tillage (Mishra *et al.*, 2011). Higher (7.7%) yield of wheat was obtained under zero tillage in comparison to conventional tillage, which is due to increase in growth period of the crop, leading to increase in number of effective tillers, grains ear^{-1} and 1000-grain weight (Mishra *et al.*, 2011,Sardana *et al.*, 2002, Yadav *et al.*, 2005 and Imran *et al*., 2013). Zero, reduced and conventional tillage recorded statistically similar grain yield (Samra *et al*.,2002).This may be attributed to the timely planting of wheat which reduced the estimated 1 per cent loss day^{-1} ha^{-1} of wheat yield due to late planting. Increase in 1% yield of wheat was recorded with the practice of reduced tillage as compared to conventional method (Tendon, 1985). As it was reported that early sowing of wheat more than 30 days before conventional sowing was reported to increase the yield of wheat by an average of 11 per cent, introduction of wheat sowing without seedbed preparation is beneficial in improving wheat productivity by sowing wheat in time. This technology improved the grain yield by about 20 per cent over farmers practice entirely under farmers' conditions as reported by Howard, 1924.

Adoption of Zero Tillage in cereal cropping system in the IGP has been reported to advance the planting time (Erenstein *et al*. 2012) thereby increasing the thermal window for wheat thus escaping from terminal heat effect. The growth attributes like numbers of tillers, effective tillers per square meter and ear length were found to be highest in conventional tillage with mulching which was at par in crop sown with conventional tillage without mulching but significantly higher than zero tillage in standing stubbles after removal of loose straw (Davinder,2010).The elimination of wet tillage in rice as a result of zero tillage had significant yield benefit on subsequent wheat due to better germination and elongated rooting of wheat by improving soil physical properties (Gethala *et al.*, 2011b).The water stress index and the grain yield was positively correlated in response to conservation tillage practices as grain yield was higher with increasing water stress index and vice versa (Gaetano *et al.*, 2013).The water stress index is a measure of relative transpiration rate of a plant at the time of measurement and is a function of measured plant temperature and the vapor pressure deficit which is a measurement of the dryness of the air. Hossain *et al., 2006* reported that bed planting produced more number of plants and spikes per square meter, longer spike length and maximum grain weight. than conventional methods. Grain yield and straw yield also found to be highest in bed planting due to higher yield attributes. Also significantly higher protein content was reported from bed planted wheat in comparison to conventionally sown crop. It was reported that the benefits of no-tillage and residue retention were clear right from second year and these benefits kept increasing over time. On an average, ZT in both rice and wheat crops resulted in slightly lower rice yield but significantly higher wheat yield thereby increasing system productivity by 0.63 Mg ha^{-1} year^{-1} as compared absolute conventional tillage (Jat *et al*., 2014).

Gupta *et al*. (2002) also reported 20–25% savings in irrigation water from the zero-tillage practice for wheat in rice-wheat system of IGP. Adoption of zero-tillage in rice-wheat system in this region advances planting time of both rice and wheat thus increasing rain water use efficiency, conserving soil moisture and escaping terminal heat effect in wheat, all contributing to climatic risk management and increase system productivity.

Water Management Practices and Mulching

High temperature mainly increases the transpiration of the plant. So the plants do not suffer from the heat stress as long as they meet the demand of increased transpiration. Heat stress is commonly associated with water stress. Water stressed plant conserves water by closing their stomata which in turn leads to decreased evaporative cooling and seized photosynthesis causing reduction in other metabolic activities. So water management is important during heat stress as sufficient availability of moisture in the field can mitigate the adverse impact of high temperature to some extent. It was reported that crops can withstand temperatures up to 40°C by supplying sufficient water because of meeting the transpiration demand under heat stress. But under limited water condition 40°C will kill leaves (Kajla *et al*., 2015).

The effects of irrigation on crop production are usually quantified by crop water production functions which are the relation between crop yield and amounts of water applied.The rational irrigation can considerably increase the grain yield (Huang *et al*., 2005). Excessive irrigation is not desirable as it delays the maturity, harvesting and decreased grain yield and crop WUE. Where as effective deficit irrigation may result in higher production and WUE (Jin *et al.,* 1999).On the contrary, it was reported that the application of irrigation water affects wheat yield mainly due to increased transpiration, while WUE and harvest index was not found to be affected by irrigation water (Olsen *et al*., 2000). The responses of grain yield and WUE to irrigation varied depending on the differences in soil water contents and irrigation schedules (Kang *et al.,* 2002). The use of sprinkler irrigation under heat stress conditions when the plant reached critical temperature helps in reducing high soil temperature and irrigating the crop during evening time helps the crop to recover from day heat stress. To minimize the effect of high temperature at other stages of crop the crop should not be water stressed at other stages.

The grain yield obtained with drip irrigation was 24% higher than full irrigation treatment and 59% higher than the existing rule treatment (Kharrou *et al*., 2011). The highest plant height, spike m^{-2}, spikelet $spike^{-1}$, grains spike-1 and 1000-grain weight were obtained at full irrigation (control WS) and skipping during dough and ripening stages as compared to skipping during seedling, tillering and booting (Tahar *et al.*, 2011).

However, the crop sown on 25th November with conventional tillage without mulching with one additional irrigation during post anthesis, conventional tillage with mulching + one additional irrigation during post anthesis and conventional tillage with mulching + recommended irrigation gave the similar grain yield of wheat (Davinder Singh, 2010 and Singh *et al*., 2011) **[Figure 3]**.

Mulching has been proved to increase the productivity of wheat due to its role in moisture conservation by reducing runoff and evaporation as well as modification of soil temperature.(Cakraborty *et al*., 2008;Huang *et al*.,2005; Li *et al*., 2005;Raman *et al*., 2005 and Verma *et al*., 2004).

The main advantages of mulching are organic matter and nutrient supply. The decomposition of mulch residues releases nitrogen (N) slowly which meets plant uptake than sources of inorganic N thus increasing N uptake efficiency and crop yield simultaneously reducing N leaching losses (Aulakh et al., 2000;Cerr et al., 2006,Cline et al.,2001). These are

responsible for the increase in plant yields. The other benefits of mulching are favorable changes in micro-climate within the crop fields and reduction in soil temperatures. Plant residue protects the soil surface against the splash effect of raindrops, crusting and increases aggregate stability measured by wet-sieving thereby increasing the soil organic matter content, stability and decreasing soil surface sealing. Organic matter addition also found to increase macro porosity and water infiltration rates. Mulching in combination with minimum tillage has also beneficial effect in reducing soil erosion, maintaining soil structure and conserving soil water.

Through a long-term trial in rice-wheat system in IGP, Jat *et al*. (2009b) found that retention of rice residue in rice-wheat system reduced the canopy temperature in wheat by 1–4°C than atmospheric temperature between 138–153 days after sowing (DAS). Further by growing wheat without previous rice crop residue, only slightly lower canopy temperature between 138–143 DAS and no difference between air temperature and canopy temperature between 148–153 DAS was observed. These differences were reported due to cooling effect on canopy as a result of enhanced evapotranspiration which is facilitated by soil moisture conservation with residue mulching. The straw mulching treatments was found to be effective in mitigating reduction of 1000-grains weight due to high temperatures at the late grain filling stage, especially in conventional tillage (Tang *et al.*, 2013).

In conclusion, use of organic mulches provided better soil water status and improved plant canopy in terms of biomass, root growth, leaf area index and grain yield, which subsequently resulted in higher water and nitrogen uptake and their use efficiencies and may reduce expected reduction of economic yield under adverse climate during reproductive stage of wheat.

Spray of Chemicals

Potassium plays an important role in carbohydrate formation, maintaining water balance in leaves and regulates stomataclosing, whic have a direct effect on stress resistance of the plant and its water use efficiency, resulted in producingmaximum yield attributes ultimately maximum grain yield (Meshah *et al*., 2009).So spraying of potassic fertilizers increases the potosynthates production in plant and translocation of dry matter to the grain.It was also reported that higher grain and straw yield of wheat was obtained by spraying 0.5 per cent KNO3 at 50 per cent flowering stage of the crop was reported from a number of studies (Sarkar *et al*.,1991 and Sarkar *et al*.,1990). This result may be attributed to the effect of NO_3^- in promoting the activity of cytokinin thus inhibiting the activity of abscisic acid and of K^+ on photosynthesis, carbohydrate redistribution and starch synthesis in storage organs (Kranook *et al*.,1974).It was also proved that both K^+ and Ca^{+2} gave beneficial effect on grain filling and yield of wheat when applied as foliar spray at 50 per cent flowering stage of the crop (Sarkar *et al.*, 1994). Crop sown on 25th November with zero tillage in standing stubbles after removal of loose straw and one foliar spray of KNO3 (1%) during anthesis was at par in grain yield than those obtained with conventional tillage without mulching + two foliar spray of KNO3 (1%) during anthesis produced the statistically similar grain yield (Davinder Singh, 2010 and Singh *et al.*, 2011). However, one foliar spray of KNO3 (1%) during anthesis gave the highest grain yield followed by two foliar spray of KNO3 (1%) during anthesis as compared to one extra irrigation during post anthesis and recommended irrigation **[Figure 3]**. However it was reported the the magnitude of response in terms of grain yield was higher with application of KCl + urea as compared to application of KNO3. (Khan *et al*., 2006).Foliar application of arginine with 2.5 and 5.0 mM on normal or delayed sowing wheat exhibited significant increment in yield and its components in comparison to untreated plants. (Hozayn *et al*., 2011).GA_3 also found to increase the dry matter production of winter wheat cultivars. Spraying of 1- MCP (1-Methylcyclopropene a growth

regulator) was found to increase kernel weight and number in wheat crop. This may be due to the suppression of the action of stress induced ethylene. (Malefyt *et al*.,2010)

Also, spray of zinc increased the growth and yield attributes under heat stress conditions as it provides thermotolerance to the photosynthetic apparatus of wheat (Graham and Donald, 2001). Similar results was obtained by Shahramlack *et al*., 2011.This may also may be attributed to the increased activity of superoxide dismutase which helps in maintaining membrane thermostability by scavenging the free radicals (Singh and Singh, 2011).Foliar application of thiourea also increased number of grains per spike and 100 grain weight by promoting root growth through enhancing assimilate partitioning at seedling and pre-anthesis stages (Anjum *et al*.,2011).

The response of foliar spray was better when applied at booting or flowering stage than at milking stage. Therefore, foliar sprays of potassium fertilizer, urea, Zinc, 1-MCP and GA3 can help in increasing grain yield of crop by alleviating the adverse impact of high temperature on wheat crop.

CONCLUSIONS AND FUTURE RESEARCH NEED

From the various researches, it can be concluded that terminal heat stress which affects wheat phenology and all yield attributing traits in all the major wheat growing region can be mitigated to some extent by agronomic manipulations like use of better cultivation practices with retention of crop residues/ mulching, selection of early maturing varieties, adjusting sowing time with better management practices, foliar spray of urea, Zn, GA, 2.5mM arginine 0.5% at 50% flowering and 1% during anthesis, extra irrigation during grain filling stage so that it can be possible to get stable yield of wheat under this changing climate scenario along with preventing the global warming by shifting to resource conservation technology.

Further, Plant responses and adaptation and the mechanisms underlying the development of heat tolerance, need to be better understood for breeding of heat tolerant varieties. Molecular approaches should be considered that uncover the response and tolerance mechanisms which will pave the way to engineering plants. At the field level, manipulating cultural practices can also considerably decrease the adverse effects of high temperature stress. Exogenous applications of protectants should be developed which are having beneficial effect on crops under heat stress. Otherwise, the plants should be engineered to synthesize these compounds to combat heat stress.

Table 1: Change in Total Crop Duration Due to Rise in Temperature

Rise in Temperature (°C)	Reduction in Wheat Duration (Days)
1	6
2	12
3	21
4	27
5	32

Source: (Tripathy *et al*., 2008)

Table 2: Reduction (%) in Various Wheat Traits under Heat Stress Conditions

Trait	Heat stress
Plant height	6.5
Productive tillers	-31.1
Days to heading	10.1
Days to anthesis	10.1
Days to maturity	10.7
Grain filling duration	11.3
Number of grains per spike	3.3
Grain weight per spike	16.8
Thousand grain weight	14.1
Grain yield	26.4

Source: (Sareen *et al*.,2012)

Table 3: Number of Grains/Spike and Grain Weight of Wheat Genotypes under Contrast Temperatures

Genotype	Grains/Spike			Grain Yield(g/Plant)			
	OPT	HT	RP(%)	OPT	HT	RP(%)	HSI
BW-1	41.9	34.3	81.9	4.1	2.2	52.9	0.97
BW-2	41	32.7	79.8	4.2	2.5	58.5	0.87
BW-3	52.8	45.3	85.8	4.6	3.0	64.7	0.74
BW-4	50.3	43.3	86.1	4.5	2.8	62.6	0.75
BW-5	51.2	36	70.3	4.3	1.9	44.7	1.16
MW-6	49.2	35.3	71.7	3.8	1.4	36.4	1.33
MW-7	43.3	33.4	77.1	3.7	1.8	49.8	1.05
MW-8	48.7	42.3	86.9	4.4	2.8	65.0	0.73
MW-9	50.7	37.3	73.6	3.8	2.1	55.5	0.93
ZW-10	53.3	33.1	62.1	5.1	1.7	32.5	1.41
LSD(p=0.05)	4.1	3.7		0.4	0.6		
CV(%)	6.4	6.8		8.56	6.67		

Source: (Rahman *et al.*, 2009)

*Relative Percentage(RP%) = (Yield performance under HT/Yield performance under OPT) x 100.

*Heat Susceptibility Index (S)=1-mean grain yield of genotype under stress environment/mean grain yield under stress free environment (if S<0.5,highly stress tolerant, if 0.5<s<1.0,moderately stress tolerant and if s>1.0, susceptible to stress.)

Table 4: Effect of Tillage and Crop Establishment Technique on Wheat Yield Attributes in a Rice- Wheat Rotation

Treatments	Number of Panicles Per m^2	Grains per Earhead	1000 Grain Weight (g)
CTR-CTW	274bc	36.09d	37.39b
CTR-ZTW	268c	38.40bc	38.06b
UpTPR-ZTW	293a	40.39c	40.79a
ZTDSR-CTW	304a	38.78c	38.31b
ZTDSR-ZTW	287ab	39.54c	40.60a
ZTDSR-ZTW+R	288ab	44.84a	40.58a
PBDSR-PBW	264c	42.73a	42.04a

Source: (Jat *et al*., 2014)

(CTR-Conventionally tilled rice, CTW-Conventionally tilled wheat, Up TPR- Unpuddled transplanted rice, ZTDSR- Zero tilled direct seeded rice, ZTW- Zero tilled wheat, ZTW+R- Zero tilled wheat with residue retention,

PBDSR- Dry seeding on permanent beds, PBW- Bed planted wheat)

* Within variables, means in the same column followed by different letters are significantly different from each other based on LSD 0.05.

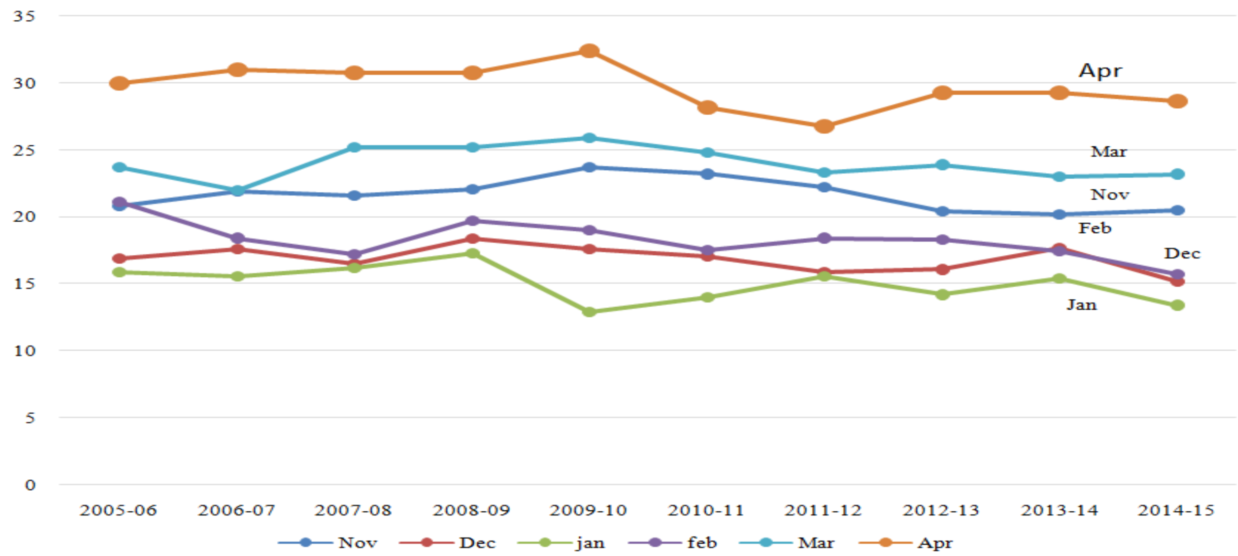

Figure 1: Average Monthly Temperature Trend for 10 Years in Varanasi during Wheat Growing Season

Source: AICRPDA, BHU

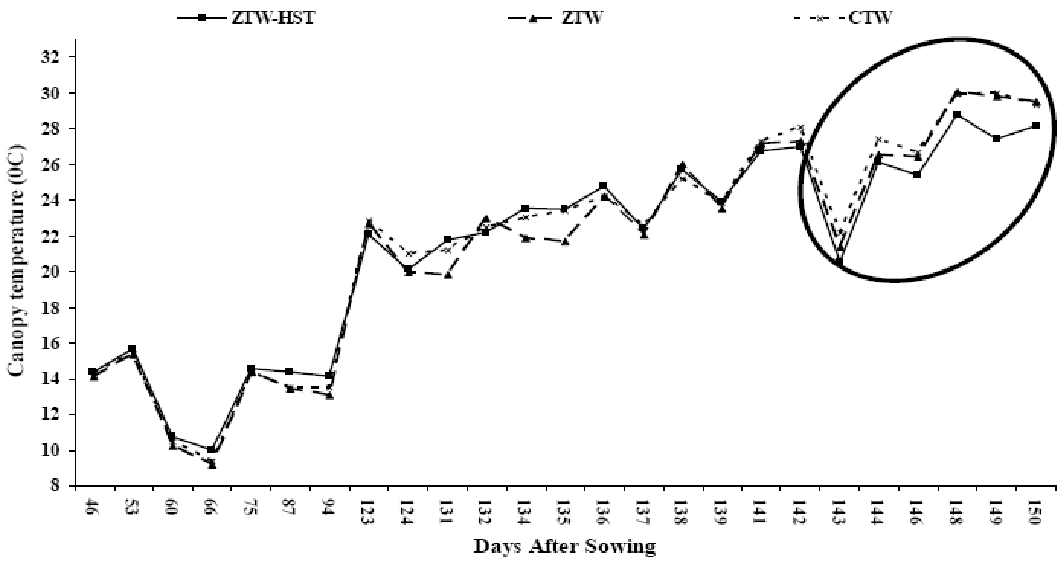

Figure 2: Effect of Tillage and Residue Management on Canopy Temperature of Wheat

Source: (Jat *et al*.,2008)

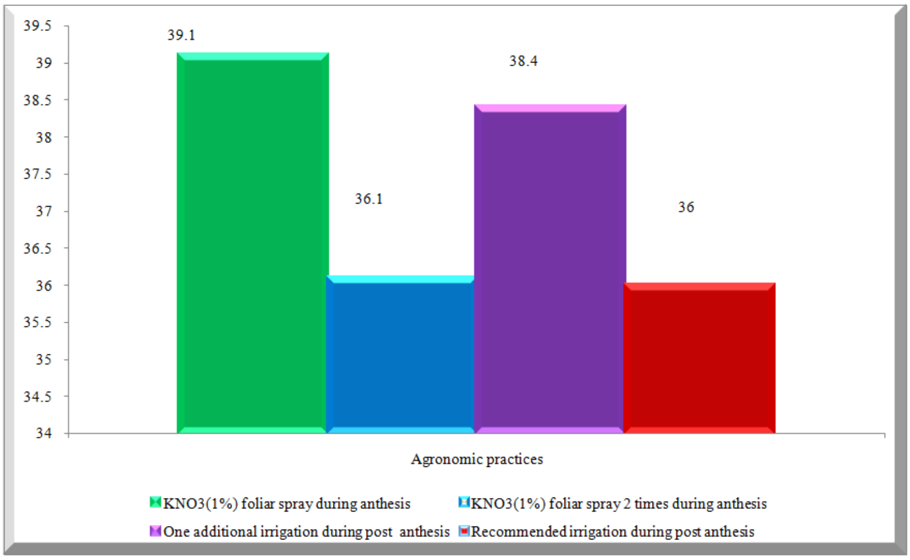

Figure 3: Effect of Agronomic Practices on Grain Yield of Wheat

Source:(Singh,2010)

REFERENCES

1. *Ali I, Shafi J, Akbar N, Ahmed W, Ali M and Tariq S. (2013). Response of wheat cultivars to different tillage practices grown under rice- wheat cropping system, Universal Journal of plant science. 1(4): 125-131.*
2. *Anjum F, Wahid A, Farooq M and Javed F. (2011) Potential of foliar applied thiourea in improving salt and high temperature tolerance of bread wheat, International Journal of Agriculture and Biology.13:251- 256.*
3. *Anonymous, (2011). Food outlook, global market analysis, (GIEWS), Global information and early warning system food and agriculture: 2.*
4. *Ashraf M. (2014). Stress-Induced Changes in Wheat Grain Composition and Quality. Critical Review. Food Science and Nutrition.54(12): 1576-1583.*
5. *Ashraf M, Harris P J C. (2013). Photosynthesis under stressful environments: An overview.Photosynthetica.51: 163-190.*
6. *Aulakh M S, Khera T S and Doran JW. (2000) Yields and nitrogen dynamics in a rice–wheat system using green manure and inorganic fertilizer. Soil Sci Soc Am J.64:1867– 1876.*
7. *Balla K, Bencze S, Bónis P, Árendás T, Veisz O. (2014). Changes in the photosynthetic efficiency of winter wheat in response to abiotic stress. Cent. Eur. J. Biol. 9: 519-530.*
8. *Barnabas B, Jager K, Feher A. (2008). The effect of drought and heat stress on reproductive processes in cereals. Plant Cell Environ 31:11–38.*
9. *Beata B, Katalin J and Attilfa F.(2008). The effect of drought and heat stress on reproductive process in cereals. Plant, cell and environment.31:11-38*
10. *Blum A, Klueva N, Nguyen H. (2001). Wheat cellular thermotolerance is related to yield under heat stress. Euphytica 117: 117–123.*
11. *Chakraborty D, Nagarajan S and Aggarwal P. (2008) Effect of mulching on soil and plant water status, and the growth and yield of wheat (Triticum aestivum L.) in a semi-arid environment. Agric Water Management. 95: 1323–1334.*

12. *Cherr C M, Scholberg J M S and Mc Sorley R. (2006) Green manure approaches to crop production: a synthesis. Agron. J. 98: 302–319.*

13. *Cline G R and Silvernail A F. (2001) Residual nitrogen and till date effects on winter cover crop growth and nitrogen content in a vegetable production system. Hort Technol.11: 219–225.*

14. *DES. (2014).Department of Economics and Statistics.*

15. *Erenstein O, Sayre K, Wall P, Helin J, Dixon J.(2012) Conservation agriculture in maize- and wheat-based systems in the (sub)tropics: Lessons from adaptation initiatives in South Asia, Mexico, and Southern Africa.*

16. *FAO. (2015).The state of food insecurity in the World.www.fao.org.*

17. *Ford MA, Pearman I and Thorne G N. (1975). Effects of variation in ear temperature on growth and yield of spring wheat. Annals of Applied Boilogy. 82: 317–333.*

18. *Gaetano A, Paolo R, Alfonso S F, Giuseppe D M, Sergio S, Antonella P and Dario G.(2013). Long-term tillage and crop sequence effects on wheat grain yield and quality. Agronomy Journal.105: 1317–1327.*

19. *Gethala M K, Ladha J K, Saharawat Y S, Kumar V, Kumar V and Sharma P K. (2011b). Effect of tillage and crop establishment methods on physical properties of a medium-textured soil under a seven-year rice–wheat rotation. Soil Sci. Soc. Am. J. 75:1851.*

20. *Graham A W and McDonald G K. (2001). Effect of Zinc on photosynthesis and yield of wheat under heat stress. Proceedings of 10th Australian Agronomy Conference. www.regional.org.au/au/asa/2001/2/c/graham.htm.*

21. *Gupta NK, Agarwal S, Agarwal VP, Nathawat NS, Gupta S, Singh G (2013). Effect of short term heat stress on growth, physiology and antioxidative defence system in wheat seedlings. ActaPhysiol Plant 35:1837–1842.*

22. *Gupta R and Seth A.(2007). A review of resource conserving technologies for sustainable management of the rice–wheat cropping systems of the Indo- Gangetic Plains (IGP). Crop Protect. 26, 436–447.*

23. *Gupta R, Narish R K, Hobbs P R and Ladha J K.(2002).Adopting conservation agriculture conservation agriculture in the rice-wheat system of the Indo-Gangetic Plains: New opportunities for saving water.In: Bouman B A M, Hengskijk H, Hardy B, Bindraban P S, Toung T P,Ladha J K, eds., Water-Wise Rice Production. International Rice Research Institute, Las Banos, Philippines. p. 356.*

24. *Hamid N, Naz B. and Rehman A. (2012). Effect of exogenous application of silicon with drought stress on protein and carbohydrate contents of edible beans. Pakistan J. Chem., 2: 99-105.*

25. *Hossain M. (2006). Effect of planting method and nitrogen levels on the yield and yield attributes of wheat. Journal bio-sciences.14: 127-130.*

26. *Howard A. (1924) Crop production in India. Oxf. univ. press, Bombay. p 100.*

27. *Huang Y, Chen L and Fu B, (2005) The wheat yields and water use efficiency in the Loess Plateau: straw mulch and irrigation effects. Agric Water Management. 72: 209–222.*

28. *Jat R K, Sapkota T B, Singh R G, Jat M L, Kumar M and Gupta R K.(2014).Seven years of conservation agriculture in a rice–wheat rotation of Eastern Gangetic Plains of South Asia: Yield trends and economic profitability. Field Crops Research.164 :99–210*

29. *Jin M G, Zhang R Q and Gao Y F.(1999) Temporal and spatial soil water management: a case study in the Heiloonggang region, PR China. Agric Water Management. 42: 173–187.*

30. *Kajla M, Yadav V K, Chhokar R S and Sharma R K. (2015). Management practices to mitigate the impact of high temperature on wheat.Journal of Wheat Research. 7(1):1-12.*

31. *Harrison PA, Porter JR, Downing TE. (2000). Scaling-up the AFRC WHEAT 2 model to assess phenological development for wheat in Europe. Agric Forest Meteoro 101: 167–186.*

32. *Hozayn M and Monem A A Abdel. (2011)Alleviation of the potential impact of climate change on wheat productivity using arginine under irrigated Egyptian agriculture. In the Proceedings of International Conference on Preparing Agriculture for Climate Change, Punjab Agricultural University, Ludhiana, on February 6-8, p 305.*

33. *IFPRI.(2009). International Food Policy Research Institute.www.ifpri.org.*

34. *Intergovernmental Panel on Climate Change (IPCC).(2007) Climate change–The physical science basis. In Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change; Cambridge University Press: Cambridge, UK.*

35. *Jat L K, Singh S K, Latare A M, Singh R S and Patel C B. (2013). Effect of date of sowing and fertilizer on growth and yield of wheat in an inceptisol of varanasi. Indian Jounal of Agronomy 58(4): 611-614.*

36. *Jat M L, Gatala M K, Ladha J K, Saharawat Y S, Jat A S, Kumar V, Sharma S K, Kumar V and Gupta R. (2009b) Evaluation of precision land leveling and double zero-till systems in the rice-wheat rotation: Water use, productivity, profitability and soil physical properties. Soil and tillage Research.105.112-121.*

37. *Jat M L, Gathala M K, Singh K K, Ladha J K, Singh S,Gupta R K, Sharma S K and Saharawat Y (2008), "Experiences with Permanent Beds in the Rice-Wheat Systems of the Western Indo-Plain", in E Humphreys and C H Roth (Eds.), Permanent Beds and Rice-Residue Management for Rice-Wheat Systems in the Indo-Gangetic Plain these Proceedings.*

38. *Joshi AK, Mishra B, Chatrath R, Ferrara G O and Singh R P. (2007). Wheat improvement in India: Present status, emerging challenges and future prospects. Euphytica. 157: 431-446.*

39. *Kang S Z, Zhang L and Liang Y L.(2002)Effects of limited irrigation on yield and water use efficiency of winter wheat in the Loess Plateau of China. Agric Water Management. 55: 203–216.*

40. *Khan M Z, Muhammad S, Nadeem M K, Akhtar E and Khalid M. (2006) Response of some wheat varieties to foliar application of N and K under rainfed conditions. Pakistan Journal of Botany. 38(4): 1027-1034.*

41. *Kharrou M. H, Salah E R, Ahmed C, Benoit D, Vincent S, Michel L P, Lahan O and Lionel J. (2011). Water use efficiency and yield of winter wheat under different irrigation regimes in a semi – arid region, Agicultural sciences. 2 :273-282.*

42. *Khichar ML, Niwas R. (2007). Thermal effect on growth and yield of wheat under different sowing environments and planting systems. Indian J Agric Res. 41: 92–96.*

43. *Kranook N P and Petibskaya V S. (1974) Effect of late top dressing on nutrient metabolism and sowing quality of grains. Byuletan Nauch-no-tekricheskoi informatsii.12.*

44. *Kumar S, Kumar R and Singh H. (2002). Influence of time of sowing and NP fertilization on grain quality of macroni wheat. Haryana Agric Univ J Res. 32: 31–33.*

45. *Laghari K A, Sial M A and Arain M A. (2012). Effect of high temperature stress on grain yield and yield components of Wheat. Science, Technology and Development. 31(2): 83-90.*

46. *Li F M, Wang J, Zhang X J. (2005) Plastic film mulch effect on spring wheat in a semiarid region. J Sust Agric. 25: 5–17.*

47. *Lobell D B, Sibley A, Ortiz-Monasterio J I. (2012). Extreme heat effects on wheat senescence in India. Nature Climite Change.2: 186–189.*

48. *Malefyt T, Mark L D, Alan W G, Hector J T and Ross D. (2010) Agronomic use of 1-MCP to mitigate the effects of stress induced ethylene. Proceedings of 37th Annual meeting of the plant growth regulation society of America: 33.*

49. *Malik R K, Kumar A, Dar SR, Sharma R, Jat M L, Singh S, (2014). On-farm impacts of agronomic management optimization on wheat productivity in a rice–wheat system of eastern Gangetic Plains of South Asia. Exp. Agric. (submitted for publication).*

50. *Malik RK, Singh S and Yadav A. (2007). Effect of sowing time on grain yield of wheat (Triticum aestivum L.) in rice–wheat cropping system. Haryana Agricultural University Journal of Research.37: 103-105.*

51. *Meshah E A E. (2009) Effect of irrigation regimes and foliar spraying of potassium on yield, yield components and water use efficiency of wheat in sandy soils, World Journal of Agricultural Sciences.5(6): 662-669.*

52. *Mishra S K, Tripathi D K, Srivastava N K, Beg M Z and Singh C.(2011). Effect of different level of nitrogen on Wheat after rice under Zero tillage.Indian Journal of Science Research. 2(3): 97-100.*

53. *Modarresi M, Mohammdi V, Zali A and Mardi M, (2010). Response of wheat yield and yield related traitsof high temperature. Cereal Research communications.38(1): 23-31.*

54. *Mukherjee D. (2012). Effect of different sowing dates on growth and yield of wheat cultivars under mid hill situation of West Bengal. Indian journal of Agronomy.57(2):152-156.*

55. *Nainwal K, Singh M.(2000). Varietal behavior of wheat (Triticum aestivum) to dates of sowing under tarai region of Uttar Pradesh. Indian J Agron. 45: 107–113.*

56. *Olesen J E, Mortensen J V and Jorgensen L N. (2000) Irrigation strategy, nitrogen application and fungicide control in winter wheat on a sandy soil. I. Yield, yield components and nitrogen uptake. J Agric Sci. 134: 1–11.*

57. *Parry ML and MS Swaminathan. (1992). Climate on food production. Mintzer (ed) confronting climate change- risk, implication and responses. Cambridge University press: 113–125.*

58. *Prasad P V V, Pisipati S R, Momcilovic I and Ristic Z. (2011). Independent and combined effects of high temperature and drought stress during grain filling on plant yield and chloroplast ef-tu expression in spring wheat. Journal of Agronomy and crop science.197(6): 430-441.*

59. *Rahman M A, Chikushi J and Saifizzaman M. (2005)Rice straw mulching and nitrogen response of no-till wheat following rice in Bangladesh. Field Crops Res. 91: 71–81.*

60. *Rahman M A,Chikushi J,Yoshida S and Karim M S.(2009).growth and yield components of wheat genotypes exposed to high temperature stress under control environment. Bangladesh Journal of Agricultural Research.34(3):361-372.*

61. *Ram A, Pannu R K and Prasad D. (2012a). Effect of management practices on growth, yield and quality of late sown Wheat. Indian journal of Agronomy. 57(1): 92-95.*

62. *Saharawat Y S, Singh, B, Malik, R K, Ladha J K, Gathala M., Jat, M L, Kumar V, (2010). Evaluation of alternative tillage and crop establishment methods in a rice–wheat rotation in North Western IGP. Field Crop. Res. 116, 260–267.*

63. *Samra J S, Dhillon S S. (2002). Relative response of sowing dates, varieties and pesticide use in relation to yield of wheat (Triticum aestivum L.). J Res Punjab Agric Univ. 39: 343–345.*

64. *Sardana V, Sharma S K and Randhawa A S. (2002). Yield performance of wheat (Triticum aestivum L.) varieties to late and very late sowing dates under the extreme north-west conditions of Punjab. Journal Research.Punjab Agricultural University.40: 177–182.*

65. *Sareen S, Tyagi BS, Tiwari V, Sharma I (2012).Response Estimation of Wheat Synthetic Lines to Terminal Heat Stress Using Stress Indices. Journal of Agricultural Science 4: 97 – 104.*

66. *Sarkar A K, Bandyopadhyay S K. (1991) Response of wheat cultivars to post-flowering foliar application of potassium nitrate solution. Indian Agric.35: 269–272.*

67. *Sarkar A K and Mukhopadhyay M. (1990) Response of rice cultivar to post-flowering foliar application of potassium nitrate solution. Indian Agric. 34: 119–122.*

68. *Sarkar A K and Tripathy S K. (1994) Effect of nitrate and its counter ions applied as post flowering foliar spray on grain filling and yield of wheat. Indian Agric. 38: 69-73.*

69. *Shahramlack, Ghooshch F and Tohidimogaddam H, (2011) Effect of zinc spraying on yield and yield components of wheat under drought stress conditions. In the Proceedings of International Conference on Preparing Agriculture for Climate Change, Punjab Agricultural University, Ludhiana, on February 6-8, p 307.*

70. *Sharma RK, Tandon JP. (1997) Investigation on heat tolerance during vegetative and grain filling phase in wheat. Crop Res Hissar 14: 2, 269–274.*

71. *Sharma SN. (2000). Wheat. In: Rathore PS (Ed.), Techniques and management of field crop production. Agrobios, India, ISBN: 9788177541755.17:171-126.*

72. *Shivani, Verma U N and Kumar S. (2003). Growth analysis of wheat (Triticum aestivum)*

73. *cultivars under different seeding dates and irrigation levels in Jharkhand. Indian Journal of Agronomy.48: 283–286.*

74. *Singh A, Singh D and Gill BS. (2011) Planting time, methods, and practices to reduce the deleterious effects of high temperature on wheat. In the Proceedings of International Conference on Preparing Agriculture for Climate Change, Punjab Agricultural university, Ludhiana, February 6-8.p 338-339.*

75. *Singh B and Singh B K (2011) Effect of reduced seed and applied zinc on zinc efficiency of wheat genotypes under zinc deficiency in nutrient solution culture. J Plant Nutr 34:449–464*

76. *Singh D. (2010) Studies to moderate the heat stress effects on wheat (Triticum aestivum L.) productivity. M.Sc. Thesis, Punjab Agricultural University, Ludhiana.*

77. *Singh P, Abraham T and Singh S S. (2008). Response of wheat to zero till sowing under rice –wheat cropping system. Proceedings International workshop on Herbicide resistance management and Zero tillage in rice-wheat cropping system: 105-106.*

78. *Singh T and Dhaliwal G S. (2000). Performance of wheat varieties under late sowing conditions in southwestern region of Punjab. Journal Research Agricultural University. 37: 181–183.*

79. *Tahar Al, Ali B, Hwary E L and Samia O Y. (2011). Effect of skipping irrigation on growth, yield, yield components and water use efficiency of wheat in semi arid Region of sudan. Agriculture and Biology Journal of North America. 2(60): 1003-1009.*

80. *Tahir I S A, and Nakata N. (2005). Remobilization of nitrogen and carbohydrate from stems of bread wheat in response to heat stress during grain filling. J. Agron. Crop Sci. 191: 106–115.*

81. *Tang Y, Xiaoli W, Chaosu L, Chun W, Xiaoling M and Gang H. (2013) Long-term effect of year-round tillage patterns on yield and grain quality of wheat. Plant Production Science. 16(4): 365-373.*

82. *Tendon J P. (1985) Wheat improvement programme for the hotter parts of India. In wheat for more tropical environments. In the Proceedings of International Symposium. Pp 63- 67. CIMMYT, Mexico.*

83. *Theilert W. (2006). A unique product: The story of imidacloprid stress shield.Pflanzenscutz Nachrichten Science Forum Bayer, 59.73-86.*

84. *Torbica A and Jasnamastiloric.(2008). Influence of different factors on wheat proteins quality. Food and Feed Research.35(2): 47-52.*

85. *Triboi E, Martre P, Triboï-Blondel A M. (2003). Environmentally- induced changes in protein composition in developing grains of wheat are related to changes in total protein content. Journal of Experimental Botany.54: 1731–1742.*

86. *Tripathy, Rojalin, S.S. Ray and A.K. Singh (2008), "Analysing the Impact of Rising Temperature and CO2 on Growth and Yield of Major Cereals Crops using Simulation Model", Paper presented at Workshop on Impact of Climate Change on Agriculture, 17-18 December, 2009, organised by Space Applications Centre (ISRO) and Indian Society of Remote Sensing, Ahmedabad.*

87. *Trnka M, Dubrovsky M, Semeradova D and Zalud Z. (2004). Projections of uncertainities in climate change scenarios into expected winter wheat yields.Theoritical Applied Climatology 77: 229-249.*

88. *Verma M L and Acharya C L. (2004) Soil moisture conservation, hydrothermal regime, nitrogen uptake and yield of rainfed wheat as affected by soil management practices and nitrogen levels. J Indian Soc Soil Sci.52: 69–73.*

89. *Wollenweber B, Porter JR and Schellberg J (2003). Lack of interaction between extreme high temperature events at vegetative and reproductive growth stages in wheat. Journal of Agronomy and Crop Science. 189: 142– 150.*

90. *Yadav A, Malik R K, Jaipal S, Singh S, Singh R, Ram K and Singh S. (2005). Sustainability of Long term Zero- tillage in wheat and its Impact on the productivity of Rice. Proceedings of the project Workshop held on June 1-2, Hisar, India:18-22.*